REMARKS

In response to the non-final Office Action mailed January 9, 2008, applicants submit the following amendments and remarks. Applicants request reconsideration of the above-identified application in light of the remarks set forth herein. Claims 1, 3-5, 7, 8, 11-15, 17-22, 24-26, and 28-39 were pending in this application. Claims 1, 17-21, 24-26, and 28 have been amended, and new Claim 40 has been added. Therefore, Claims 1, 3-5, 7, 8, 11-15, 17-22, 24-26, and 28-40 are now pending in this application.

Claims 1, 3-5, 7, 8, 11-15, 17-22, 24-26, and 28-39 have been rejected under 35 U.S.C. § 103(a). Applicants respectfully submit that all claims are now in condition for allowance. Accordingly, applicants request reconsideration and allowance of all claims.

Interview Summary

A telephonic interview was held on June 17, 2008, between Emily Peyser, Tom Ritzdorf, Craig Bohn, and Examiner Bill Leader. The rejection of Claim 1 under 35 U.S.C. § 103(a) was discussed during the interview. In addition, the Dubin reference was discussed. No agreement was reached by the parties with respect to Claim 1; however, applicants appreciate the Examiner's time spent during the interview.

Background

A conventional electrodeposited copper film is presented in FIGURE 2 of the application. When using organic additives, such as accelerator agents, to preferentially fill recessed microstructures, a phenomenon is exhibited in which deposited metal overfills the recessed microstructure, forming an overburden of metal above the recessed features. This phenomenon has been referred to as the "momentum plating" effect. As seen in FIGURE 2, overburden "bumps" on the top of the feature can be observed. Bump heights are strongly dependent on the feature size and feature density, with large bumps on top of the small, dense features. Since the

conventional next step after electroplating is the use of a chemical-mechanical polishing technique (CMP) to planarize the wafer surface, these pattern dependent bumps can lead to uniformity problems for the CMP process. CMP may differentially polish areas of the substrate due to the raised bumps, as further complicated by different grain structures for the bumps and surrounding areas.

As can be seen in FIGURES 4a, 4b, and 4c, the trenches were preferentially filled during the initial deposition (FIGURE 4a) and the preferential deposition in the vicinity of the inlaid feature does not stop once the copper surface has become planarized (FIGURES 4b and 4c). It is almost as if the deposition process exhibits a "momentum" that carries this increased deposition rate over the nominal surface to produce a convex feature where there was initially a concave one. This effect is believed to be unique to electrodeposition in the presence of organic additives.

While not wishing to be limited to theory, a mechanism has been proposed which demonstrates the physical effects associated with the topography of the features that are produced by the momentum effect. If the suppressor adsorbs to the field area, above the etched features, and the accelerator is able to diffuse into the features and promote deposition there, it is not difficult to understand how the raised features may be formed. As illustrated in FIGURE 6a, the accelerator ("A") is more concentrated inside the feature due to the inability of the suppressor ("S") to migrate to this area and its occupation of the active sites in the field region. The suppressor does continue to diffuse into the feature at some rate, however, where it is incorporated into the film as copper is deposited.

This causes a localized depletion in the concentration of the suppressor near the feature top and a relative abundance of suppressor over the majority of the field region of the wafer. Because this creates a situation as illustrated in FIGURE 6b, where the concentration of

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suppressor very near the feature opening is depleted at the moment the surface becomes planar, the deposition rate in this area is greater than that in the field region. This dynamic situation caused by the diffusion gradients in the system provides a possible explanation for the momentum plating effects typically observed.

However, if the mechanism is as discussed in the preceding paragraph, one should expect to see the bumps eliminated by simply pausing the deposition at or near the point of planarizing the features for a time sufficient to allow diffusion to create a uniform surface concentration of additives, then proceeding with the deposition. In fact, when the inventors perform this experiment, there is surprisingly little or no effect on the bump height above the trenches found. The inventors have found that in developing the present invention the wafer (workpiece) can be completely removed from the plating solution, rinsed and dried, then returned to the reactor for completion of deposition, with no obvious reduction of the bumps. This indicates that a property of the deposited film itself contributes to the profile evolution. The inventors postulate, without limitation by theory, that it is the incorporation of the additives in the metal film as it is being deposited that causes the effect to be so persistent.

Brief Description of Embodiments of the Present Invention

The embodiments of the present invention are directed to processes and apparatuses for applying a forward plating power to cause metal ions to be deposited from the plating bath and/or anode onto the substrate, followed by applying a reverse plating power, at a level and for a sufficient second period of time, so as to limit the formation of an overburden plating bump over the recessed feature by substantially desorbing organic additives, such as accelerators, from the deposited metal structure.

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Claim Rejections Under 35 U.S.C. § 103(a)

Claims 1, 3-5, 7, 8, 11-15, 17-22, 24-26, 28-31, 33-37, and 39 stand rejected under 35 U.S.C. § 103(a) as being unpatentable over U.S. Patent No. 5,972,192, issued to Dubin et al. (hereinafter "Dubin"), combined with either U.S. Patent No. 6,245,676, issued to Ueno (hereinafter "Ueno"), or newly cited U.S. Patent No. 2,678,909, issued to Jernstedt et al. (hereinafter "Jernstedt"), and further in view of U.S. Patent No. 5,328,871, issued to Ding et al. (hereinafter "Ding"), with either U.S. Patent No. 5,223,118, issued to Sonnenberg et al. (hereinafter "Sonnenberg") or U.S. Patent No. 3,770,598, issued to Creutz (hereinafter "Creutz"). In addition, Claim 32 stands rejected as being unpatentable over the previously cited references in view of U.S. Patent No. 5,969,422, issued to Ting et al. (hereinafter "Ting"). Moreover, Claim 38 stands rejected as being unpatentable over the previously cited references in view of U.S. Patent No. 6,251,251, issued to Uzoh et al. (hereinafter "Uzoh"). Applicants respectfully disagree with the rejections.

To establish a *prima facie* case of obviousness, the cited prior art references must teach or suggest all the claim elements. In addition, there must be some apparent reason, either in the references or in the knowledge of one skilled in the art, to modify the reference or to combine the elements of multiple references with a reasonable expectation of success.

Claims 1, 3-8, 11-15, 17-22, 24-26, and 28-39 are generally directed to methods and apparatuses for limiting the deposition of momentum plating overburden bumps generally formed above recessed features when organic additives, particularly accelerator agents, are used to preferentially fill recessed microstructures.

Claim 1 generally recites (a) exposing the surface of the workpiece to an electroplating bath including a source of metal ions to be deposited on the surface and an organic additive that influences the metal ions to be preferentially deposited within the recessed microstructures

relative to a surrounding surface, the recessed microstructures including a sidewall, bottom surface and an opening opposite the bottom surface, wherein the organic additive comprises an accelerator agent; (b) supplying net forward electroplating power between the surface of the workpiece and an anode disposed in electrical contact with the electroplating bath for a first time period, the first time period and a level of forward electroplating power supplied during the first time period are selected such that metal ions are deposited within the recessed microstructures to at least partially fill the recessed microstructures during the first time period; and (c) when the fill in the recessed microstructures is at or near the point of planarization, reversing the electroplating power supplied between the anode and the surface of the workpiece for at least a portion of a second time period, the second time period being greater than or equal to ten seconds, the second time period and a level of reverse electroplating power supplied during the second time period are selected to substantially desorb accelerator agent from the deposited metal structure to limit deposition of a bump in an overburden over the at least partially filled recessed microstructures relative to the surrounding surface.

Claim 24 generally recites: (a) exposing the surface of the workpiece to an electroplating bath including a source of metal ions to be deposited on the surface and an accelerator agent that is adsorbed on the surface and influences the metal ions to be preferentially deposited within the recessed microstructures relative to the remainder of the surface, the recessed microstructures including a sidewall, bottom surface and an opening opposite the bottom surface; (b) supplying net forward electroplating power between the surface of the workpiece and an anode disposed in electrical contact with the electroplating bath for a first time period and at a first level of supplied power selected so that metal ions are deposited to at least partially fill the recessed microstructures; (c) pausing the metal deposition at or near a level of fill planarization by reversing the electroplating power supplied between the anode and the surface of the workpiece

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during at least a portion of a second time period that is greater than or equal to ten seconds, the second time period and a second level of applied power selected to limit the deposition of further metal ions over the at least partially filled recessed microstructures relative to the remainder of the surface and to desorb the accelerator agent from the deposited metal structure to limit the development of a bump in an overburden of metal over the at least partially filled recessed microstructures; and (d) supplying net forward electroplating power between the surface of the workpiece and an anode disposed in electrical contact with the electroplating bath for a third time period and at a third level of supplied power selected so that metal ions are deposited to substantially fill the recessed microstructures.

Claim 25 generally recites: (a) exposing the surface of the workpiece to an electroplating bath including a source of metal ions to be deposited on the surface and an accelerator agent; (b) supplying net forward electroplating power between the surface of the workpiece and an anode disposed in electrical contact with the electroplating bath for a first period of time and under a first set of plating process parameters such that metal ions are preferentially deposited within the recessed microstructures relative to the remainder of the surface to at least partially fill the recessed microstructures during the first time period, the recessed microstructures including a sidewall, bottom surface and an opening opposite the bottom surface; and (c) when the fill in the recessed microstructures is at or near the point of planarization, supplying electroplating power between the anode and the surface of the workpiece during a second time period in a series of forward plating power pulses interspersed with reverse plating power pulses to substantially desorb the accelerator agent from the deposited metal structure and limit the deposition of a bump in a metal overburden over the at least partially filled recessed microstructures relative to the remainder of the surface, the second time period being greater than or equal to ten seconds.

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Claim 26 generally recites: (a) exposing the surface of the workpiece to an electroplating bath including a source of copper ions, an acid, a source of chloride ions and an organic additive that influences copper ions to be preferentially deposited within the recessed microstructures relative to the remainder of the surface, the recessed microstructures including a sidewall, bottom surface and an opening opposite the bottom surface, wherein the organic additive comprises an accelerator agent and does not include a leveling agent; (b) supplying net forward electroplating power between the surface of the workpiece and an anode disposed in electrical contact with the electroplating bath for a first period of time and at a first level of supplied power such that copper ions are preferentially deposited within the recessed microstructures relative to the remainder of the surface to at least partially fill the recessed microstructures during the first period of time; and (c) supplying electroplating power between the anode and the surface of the workpiece during a second time period in a series of forward plating power pulses interspersed with reverse plating power pulses to substantially desorb the accelerator agent from the deposited metal structure and limit the deposition of a bump in a metal overburden over the at least partially filled recessed microstructures relative to the remainder of the surface, the second time period being greater than or equal to ten seconds.

Claim 28 generally recites an electroplating apparatus for applying a metal structure to a surface of a workpiece defining a plurality of recessed microstructures. The apparatus generally includes a controller for controlling the power supply to supply a level of net forward electroplating power during the first time period so that the metal ions are deposited within the recessed microstructures to at least partially fill the recessed microstructures during the first time period and, when the fill in the recessed microstructures is at or near the point of planarization, to supply a level of reverse electroplating power for at least a portion of a second time period to substantially desorb the accelerator agent from the deposited metal structure and limit the

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deposition of a bump in a metal overburden over the at least partially filled recessed microstructures relative to the remainder of the surface, the second time period being greater than or equal to ten seconds.

Applicants submit that the cited references, whether alone or in any combination, fail to teach or suggest all of the elements of the claims at issue. In that regard, Dubin is generally directed to voidlessly filling features having high aspect ratio openings, e.g., aspect ratios greater than 3.1, with improved uniformity and large grain size for improved reliability and increased electromigration resistance. *See* Dubin, Column 4, lines 31-39. Ding, Sonnenberg, and Creutz are all cited in the Office Action as purportedly teaching the use of additives to improve copper deposits.

Applicants reiterate that Dubin does not so much as contemplate the phenomenon of "momentum plating," which, as described above, is the problem that embodiments of the present invention are designed to solve. In fact, Dubin uses forward pulse plating and/or forward reverse plating to continuously plate and deplate copper by cathodically plating copper or copper alloy and anodically dissolving a portion of the deposited copper or copper alloy so that the thickness at the corners of the structure is the same as or less than the thickness at the walls, then completing the fill by cathodic plating. Such a method is designed to enhance uniform deposition, as described at Column 7, lines 5-15 and 25-36 (bold and italics added for emphasis):

> During the first electroplating phase, Cu or a Cu alloy is electroplated ***to a thickness of about 1/2 of the opening (contact, via or trench) width***, employing DC, forward-reverse or forward pulse plating. During the second electro-etching phase, the thickness of deposited copper is reduced by anodic dissolution by employing anodic DC or pulse dissolution [e.g., reverse pulse or reverse-forward pulse] to have about the same or smaller Cu thickness at the corners of openings than that on the side walls. During the third electroplating step, cathodic current is employed (DC, forward pulse or forward-reverse pulse) to fill the openings.
> ...
> The precise mechanism underpinning the present invention whereby a high aspect ratio opening is filled from the bottom progressively upwardly is not known.

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> However, while not wishing to be bound by any particular theory, it is believed that, as a result of diffusion, a smaller concentration of the ***leveling agent*** is established at the bottom of the opening, resulting in a relatively high deposition rate at the bottom of the opening which deposition rate decreases upwardly, due to suppression of electrodeposition by the increasing concentration of leveling agent. Pulse plating and/or forward-reverse plating enhances uniform deposition commencing at the bottom of the opening and progressing upwardly, yielding deposits exhibiting a larger grain size.

Therefore, Dubin teaches partially filling an opening to a thickness of about 1/2 of the opening width. With an aspect ratio at a minimum value of 3.1, such fill after the first forward plating step would be about 16% of the depth of the recess. (Notably, with increased aspect ratios in the recesses, the percentage of fill after the first forward plating step will be less than 16% of the depth of the recess.) After such fill, Dubin teaches using an anodic step to partially dissolve the metal structure so as to enhance uniform deposition in the feature, which is believed to be hindered by increasing leveling agent concentration as deposition progresses upwardly.

Applicants disagree with the obviousness rejection over Dubin because Dubin fails to teach or suggest reversing the electroplating power for at least a portion of a second time period when the fill in the recessed microstructures is at or near the point of planarization to substantially desorb accelerator agent from the deposited metal structure to limit deposition of a bump in an overburden over the at least partially filled recessed microstructures relative to the surrounding surface, as generally recited in amended Claims 1, 24, 25, and 28 and the claims depending therefrom, without requiring dissolution of the metal structure. In contrast, Dubin teaches partially filling an opening to a thickness of about 1/2 of the opening width, then reversing electroplating power to partially dissolve the metal structure and enhance uniform deposition in the feature.

Moreover, regarding amended Claim 26, Dubin fails to teach or suggest an electroplating bath including a source of copper ions, an acid, a source of chloride ions, and an organic

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additive, wherein the organic additive includes an accelerator, but not a leveling agent, as generally recited in amended Claim 26.

Applicants further submit that Ding, Sonnenberg, and Creutz fail to cure the deficiencies of Dubin. Therefore, applicants respectfully submit that the cited references--Dubin, Ding, Sonnenberg, and Creutz--whether cited alone or in any combination, fail to teach or suggest all of the claim elements of the claims at issue.

As the Office Action admits, Dubin does not specify any time requirement to perform its anodic etching step. The Office Action argues that there is nothing in Dubin to suggest that the etching step must be performed in less than 10 seconds, and even so, the Office Action states that Ueno shows that a pulse time period of 10 seconds for reverse power is known in the art, discussed below.

Applicants submit that there is no apparent reason to combine Dubin and Ueno to arrive at the claimed invention, and even if the references were combinable, Ueno still fails to cure the deficiencies of Dubin. Ueno teaches using a plating current pattern and a *retarding agent* to control the copper plating. As described in Ueno, at Column 9, lines 42-47, "a positive pulsed current is a back bias current to remove additive molecules that are adsorbed at a high current density portion, and hence the copper plated layer is more deposited at a high current density portion by conducting the positive pulsed current." By removing *retarding agent* additive molecules (which would suppress deposition) by conducting positive (or reverse) pulsed current, an increase in net deposition of copper is achieved by Ueno.

Applicants submit that there is no apparent reason to combine Dubin and Ueno because the suggested combination of references would change the basic principle under which Dubin was designed to operate, that is, using a reverse pulse plating step to partially dissolve the copper structure, and not, as taught by Ueno, to *increase* net deposition of copper by supplying positive

(or reverse) pulsed current. Even so, Ueno still fails to teach or suggest reversing the electroplating power for at least a portion of a second time period when the fill in the recessed microstructures is at or near the point of planarization to substantially desorb accelerator agent from the deposited metal structure to limit deposition of a bump in an overburden over the at least partially filled recessed microstructures relative to the surrounding surface, as generally recited in amended Claims 1, 24, 25, and 28, and wherein the organic additive includes an accelerator, but not a leveling agent, as generally recited in amended Claim 26.

Moreover, applicants reiterate that, in contrast to embodiments of the present invention, Ueno teaches the formation of an overburden as desirable. As noted in Ueno at Column 8, lines 25-32, referring to Figures 1A-C and 2A, after trenches 14-1 to 14-n are filled, plating continues in order to purposefully produce an overburden above the filled trenches 14-1 through 14-n. *See also* Column 4, lines 14-21. According to Ueno, the formation of this overburden is desirable to avoid the undesirable erosion and dishing of the surface of the interlayer insulating film 12 illustrated in Figure 10 and described at Column 3, lines 31-44. Thus, Ueno teaches that it is desirable, not undesirable, to form an overburden over recessed microstructures.

Therefore, applicants respectfully submit that there is no apparent reason to combine Dubin and Ueno to arrive at the claimed invention, and even if there was, Ueno still fails to cure the deficiencies of Dubin. Applicants further submit that Ding, Sonnenberg, and Creutz also fail to cure the deficiencies of Dubin. Accordingly, the claims at issue are not obvious over the cited references--Dubin, Ueno, Ding, Sonnenberg, and Creutz--whether cited alone or in any combination. For at least these reasons, applicants respectfully request withdrawal of the rejections of the claims.

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New Claim

New Claim 40 has been added. Support for new Claim 40 can be found in U.S. Patent No. 4,673,469, issued to Sonnenberg et al., expressly incorporated by reference in the application in the paragraph beginning at page 12, line 10.

CONCLUSION

In view of the foregoing amendments and remarks, applicants respectfully submit that the present application is in condition for allowance. The Examiner is invited to contact the undersigned representative with any remaining questions or concerns.

Respectfully submitted,

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